MASTER

FUNDAMENTAL RELATIONSHIPS OF NATURAL VENTILATION

1. The Forces

The forces which give rise to natural ventilation are the difference of wind pressures on exposed surfaces and the difference of hydrostatic pressures resulting from a temperature difference of the air inside and outside a building.

2. Relation of the flow to the head producing it.

The force moving the air may be expressed as a "head" or the height through which unit mass of air must descend in order to overcome the resistance offered to its passage through the system.

The volume of air passing through the system is proportional to the air velocity. The production of kinetic energy requires work proportional to the square of the velocity produced, and we may write

$$H = RV^2$$

where H = the head

R = the resistance of the system to the flow = a constant

V = the flow or volume of air passing through the system in unit time.

The effects of friction have been neglected.

3. Equation of continuity

If there may be no accummulation of air within the system we may write

$$V\rho = \text{constant}$$

where ρ is the air density.

The velocities and pressure differences encountered in natural ventilation systems are small, their effect on the density of the air is slight and compressibility may be ignored. The effect of temperature differences on the density of the air is greater, but still small. Since it is convenient to assess the flow of air through a system by measuring the volume rather than the mass of air passing, it is usual to assume ρ = constant and to write

$$V = \text{constant}$$

i.e. that the volume of air passing in unit time is the same for all cross sections of the system. The consequences of assuming ρ = constant are within the limits of measurement of V. We note however that the effect of pressure differences on air density and on air movement are of a different order.

4. Head due to wind pressure

The total thrust on a surface facing a moving airstream consists of the existing static pressure plus a pressure arising from the impact of the airstream. If the flow is brought to rest at some point on the surface, the impact pressure at that point is given by Bernouilli's equation for an incompressible fluid viz.

/ Impact pressure

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Impact pressure + static pressure = total head = constant

$$1/2\ \rho v^2 + p = C$$

where v = air velocity

p = static pressure

If H is the head appropriate to the impact pressure, the work done in the descent of unit mass of air through H cms = gH ergs.

The force due to impact pressure is $1/2\ \rho v^2$ dynes/cm^2 (where v is in cm/sec) and the work done when this force moves the volume of air appropriate to unit mass through the system is $1/2\ \rho v^2 \times 1/\rho$ ergs.

$$\therefore \quad gH = 1/2\ v^2$$

$$H = v^2/2g \quad \text{"CMS of air"}$$

If v is measured in m.p.h.

$$H = v^2/2g \left(\frac{5280 \times 12 \times 2{\cdot}54}{3600}\right)^2 1/2{\cdot}54 \quad \text{"ins of air"}$$

or

$$H = v^2/2g \left(\frac{5280 \times 12 \times 2{\cdot}54}{3600}\right)^2 \rho/2{\cdot}54 \quad \text{"ins of water"}$$

where ρ = air density.

$$H \simeq {\cdot}00051\ v^2 \quad \text{"inches of water"}$$

5. Head due to stack pressure

The movement of air due to a temperature difference inside and outside a building is known as the stack effect.

If T and T + ΔT are the temperatures, measured in degrees centigrade, outside and inside a building and ρ_o and ρ_i are the corresponding densities, then the pressure difference effecting flow through apertures having a vertical separation of h cms is $(\rho_o - \rho_i)\ g\ h$ dynes/cm^2.

If H is the appropriate head

$$gH = (\rho_o - \rho_i)\ gh \times 1/\rho_i$$ = work done in moving unit mass of air through the system.

$$H = \left(\frac{\rho_o - \rho_i}{\rho_i}\right)h \quad \text{"cm of air"}$$

$$H = \frac{\Delta T}{T}\ h \quad \text{"ft of air"}$$ where h measured in feet.

$$H = \rho_o \frac{T.\ 12h}{460 + T} \quad \text{"ins of water"}$$ when T measured in degrees Fahrenheit and h in feet.

$$H \simeq .0145\ \frac{Th.}{460 + T} \quad \text{"ins of water"}$$

6. Combination of resistances

(i) Resistances in series

We consider a simple system with inlet and outlet, each having

/ resistance,

resistance, and an intermediate ventilated space having no resistance. The total head H may be divided into two parts, h_1 spent in carrying air through the inlet and h_2 spent in carrying air through the outlet. Let R_1, R_2 be the resistances of the inlet and outlet respectively and R the equivalent resistance of the complete system. Let V be the flow through the system.

For the whole system $H = RV^2 = h_1 + h_2$

For the inlet and outlet $h_1 = R_1 V^2$

$h_2 = R_2 V^2$

and $R = R_1 + R_2$

(ii) Resistances in parallel

Let V_1, V_2 by the flow through parallel channels of resistance R_1, R_2 respectively. The head is the same for each channel and the total flow through the system is given by

$$V = V_1 + V_2$$

and $$H = RV^2$$

but $$H = R_1 V_1^2 = R_2 V_2^2$$

Hence $$(1/R)^{\frac{1}{2}} = (1/R_1)^{\frac{1}{2}} + (1/R_2)^{\frac{1}{2}}$$

(iii) Equivalent thin plate aperture

It may be shown that the resistance to flow of a thin plate aperture (having a coefficient of discharge = 0.65) is given by

$$R = 1/27\alpha^2$$

Where α is the area of the aperture in squarefeet.

If the rate of flow through a component of a system is known, together with the head across it, the area of the thin plate orifice to which the component may be regarded as equivalent can be calculated.

For components in series e.g. an inlet and outlet with an intermediate ventilated space, the equivalent area of the combination, α, is given by

$$\frac{1}{\alpha^2} = \frac{1}{\alpha_1^2} + \frac{1}{\alpha_2^2}$$

where α_1, α_2 are the equivalent areas of the apertures.

For components in parallel e.g. as in a wall having more than one aperture, the equivalent area of the combination α is given by $\alpha = \alpha_1 + \alpha_2$ where α_1, α_2 are the equivalent areas of the apertures.

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